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RESEARCH MEMORANDUM

PRELIMINARY INVESTIGATION OF THE SUPERSONIC FLOW FIELD DOWNSTREAM OF WIRE-MESH NOZZLES IN A CONSTANT-AREA DUCT

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PRELIMINARY INVESTIGATION OF THE SUPERSONIC FLOW FIELD DOWNSTREAM OF WIRE-MESH NOZZLES IN A CONSTANT-AREA DUCT

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SUMMARY

An investigation was conducted in a 3.4- by 3.4-inch duct to determine some characteristics of the supersonic flow downstream of four wire-mesh screen nozzles with nominal design Mach numbers in the range between 1.97 and 2.58. Visual data, transverse Mach number and static-pressure distributions at several axial stations, the total-pressure loss across the screens, and axial static-pressure gradients were used to evaluate the flow.

Two types of disturbance were observed in the flow field: a fine network of interacting expansion and compression waves which formed immediately downstream of the screens and appeared to dissipate within 25 to 40 wave intersections; and relatively strong oblique shock waves that originated at the junctions of the screens and the walls and were reflected throughout the length of the duct. The distance required for the network of waves to dissipate appeared to decrease with increasing density of the interactions. Regions of fairly uniform flow existed beyond the network in central regions of the shock diamonds.

The total-pressure loss across the screens (from 22 percent at Mach number 1.58 to 43 percent at Mach number 2.06) recorded at axial stations where the flow was considered most uniform was very large compared with the loss across conventional two-dimensional nozzles. The corresponding Mach numbers (approximately 80 percent of nominal values predicted by one-dimensional isentropic theory over range investigated) reflected, in part, these losses.

INTRODUCTION

Among the different nozzle configurations considered for obtaining supersonic flow in a wind tunnel, the multinozzle has attracted interest because of its short length. Investigation of a conical multinozzle consisting of a metal plate with convergent-divergent holes (reference 1) indicate the possibility of obtaining uniform flow at some distance downstream of such a unit, but at the expense of a high loss in total pressure. Tests with two-dimensional grating nozzles, also reported in reference 1, reveal severe wake effects resulting from vortices shed from the trailing edges of the grates, though the pressure losses were appreciably lower than those across the perforated plate.

Upon the suggestion of Dr. John Evvard of the NACA Lewis laboratory, a preliminary investigation was conducted with nozzles made of wire mesh to determine the feasibility of using such simple units to establish supersonic flow. Although appreciable pressure losses might be expected 2227
across this extreme case of the multinozzle, it was reasoned that the wake effects would dissipate a short distance downstream of the screen and thus leave regions suitable for some types of investigation. Such nozzles might provide a means of varying the turbulence level in a supersonic stream. Accordingly, four wire-mesh screens with design Mach numbers in the range between 1.97 and 2.58 were investigated. The flow field was determined with the aid of schlieren photographs, transverse Mach number and static-pressure distributions at several stations downstream of the screens, and the axial static-pressure gradients. The loss in total pressure across each screen was determined at the axial location where the flow was considered most uniform. Two of the screens had the same design Mach number (2.18), but with different meshes and wire diameters so that the effect of changing the number of holes and the wire size at one Mach number could be ascertained.

SYMBOLS

The following symbols are used in this report:

d wire diameter, (in.)

m mesh (holes/in.)

M Mach number

p static pressure

P total pressure

Subscripts:

0 conditions upstream of screen

1 free-stream conditions in plane of probe traverse

d nominal design

w wall

APPARATUS

The investigation was conducted in the 3.4- by 3.4-inch constant-area duct illustrated in figures 1 and 2. Four different sizes of stainless-steel mesh were investigated. Principal design parameters are listed in the following table:

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Mesh, m (holes/in.)	Wire diameter d, (in.)	Mesh-wire diameter product, md	Free-area ratio	Nominal design Mach number, M_d
20	0.011	0.220	0.606	1.97
18	.016	.288	.506	2.18
9	.032	.288	.506	2.18
15	.028	.420	.350	2.58

The free-area ratio is the ratio of open area to total area of a piece of wire mesh. Because of the complex shape of the holes in each screen, a rigorous theoretical prediction of the flow downstream of the screen was not attempted and the nominal design Mach number was determined directly from the free-area ratio assuming one-dimensional isentropic flow.

Each nozzle, except for the one designed for Mach number 2.58, was fixed with solder in a recess in a screen holder so that the exposed area equaled the duct area. No other attention was given to the joint between the screen and the walls of the duct. The exposed section of the Mach number 2.58 screen was 3.2 inches square with the sides set in 0.1 inch from the walls of the duct.

The static and total pressures in the duct along a transverse center line at several axial stations were determined with the probes illustrated in figure 2. In addition, small orifices were spaced along the center line of one duct wall to measure the axial static-pressure gradient. A pitot tube was utilized to measure the total pressure upstream of the screen. Schlieren photographs were obtained with a movable schlieren system which permitted observation of the flow over most of the duct length.

The dew point upstream of the nozzle was maintained at 0° ±10° F and the air total temperature generally at 150° ±20° F, although some tests were conducted at temperatures as low as 90° F when the temperature effect upon the flow was found to be negligible. The total pressure upstream of the nozzle was approximately atmospheric. Pressures were recorded on a mercury manometer board and were read to the nearest 0.05 inch.

DISCUSSION OF RESULTS

Schlieren Photographs

The schlieren photographs of the flow downstream of the screens (fig. 3) were taken with the knife edge positioned for maximum sensitivity. Two types of disturbance were observed: The interacting expansion and compression waves originating at the screens, called mesh disturbances, and strong oblique shock waves that originated at the junctions of the screens with the duct walls, referred to as corner shocks.

In general, the mesh disturbances dissipated within 25 to 40 wave intersections. The actual distance appeared to decrease with increasing density of the interactions (a function of mesh size and nominal design Mach number). Thus the lowest nominal design Mach number screen, which also had the finest mesh, had the shortest dissipation distance. Also, of the two nozzles with a design Mach number of 2.18, the one with the finer mesh appeared to require a shorter distance for dissipation of the mesh disturbances. The corner shocks presumably resulted because no particular attention was given to the orientation of the individual wire strands relative to the walls combined with the presence of initial boundary layer. Although no attempt was made to improve the nozzle geometry at the duct walls, the periphery of the highest design Mach number screen was set in 0.1 inch from the walls in an effort to fan out the corner shocks and thus speed their dissipation. The only significant effect of this modification was to increase the stream Mach number as a result of the increased expansion. Increasing frequency of interaction of the corner shocks with distance downstream is indicative of the negative axial Mach number gradient present in the duct.

Mach Number and Static-Pressure Distributions

The variations of Mach number and static pressure along a transverse center line at several axial stations are presented in figures 4 and 5 for the four screens. The stations were chosen so that the flow could be investigated at different positions in the corner shock pattern. Each dashed line indicates the distance from the wall to the nearest corner shock as observed in figure 3.

Mach number distributions indicated the same general flow pattern to exist downstream of each nozzle (fig. 4(a) to 4(d)). Fairly uniform flow (on the order of ± 0.05) existed downstream of the mesh disturbances in central region of the shock diamonds. Data were not recorded with the lowest Mach number nozzle at 11.50 inches and with the 18-mesh nozzle designed for Mach number 2.18 at 14.88 inches because the duct choked near the plane of measurement when the probe was present. The

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magnitude of the drop in Mach number across the reflected corner shocks at 6.44 inches downstream of the Mach number 1.97 nozzle, where the plane of measurement was about 0.5 inch downstream of the intersection of the shocks, may be indicative of a shock-focusing effect similar to that observed with axially symmetric nozzles.

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The Mach number profiles for the two screens with the same design Mach number are generally the same downstream of the mesh disturbances. The dissimilarity between the profiles at 6.44 inches probably resulted because the line of pressure survey was almost coincident with the intersection of the corner shocks reflected from the windows. (If the intersection of these corner shocks at this station was not perpendicular to the duct walls, an asymmetrical Mach number profile would have been expected.)

Because inclined flow and shock waves are known to affect pressures recorded with the type of static probe used in this investigation, the accuracy of the static pressures (and therefore the calculated Mach numbers) in the vicinity of the corner shocks and the mesh disturbances is questionable. The transverse static-pressure distributions shown in figures 5(a) to 5(d) generally reflect the corner shock locations.

The axial static-pressure gradients along the center line of one wall are given in figure 6. The intersections of the corner shocks and the mesh disturbances with the wall account for the noticeable scatter. The increase in slope corresponding to an increased rate of boundary-layer growth beginning at 18 inches from the Mach number 2.58 screen may be attributable to a feedback through the boundary layer of the high pressure that existed at the end of the duct due to omission of a subsonic diffuser (see fig. 2).

The variation with mesh-wire diameter product of the mean total pressure ratio across the screens at the axial stations where the flow was considered most uniform (shown in fig. 7) indicates that the pressure loss across supersonic nozzles of the type investigated herein is very high (from 22 percent at Mach number 1.58 to 43 percent at Mach number 2.06) compared with the small losses across conventional two-dimensional nozzles. The corresponding experimental variation in Mach number shown in figure 7 (approximately 20 percent lower than the nominal design Mach number over the range investigated) reflects, in part, these pressure losses.

SUMMARY OF RESULTS

In an investigation of the supersonic flow field downstream of wire-mesh nozzles, the following results were obtained:

1. Two types of disturbance were observed in the flow field: a fine network of interacting expansion and compression waves which formed immediately downstream of the screens and appeared to dissipate within 25 to 40 wave intersections; and relatively strong oblique shock waves that originated at the junctions of the screens and the walls and were reflected throughout the length of the duct. The distance required for the network of waves to dissipate appeared to decrease with increasing density of the interactions.

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2. Regions of fairly uniform flow were present downstream of the mesh disturbances in central regions of the shock diamonds.

3. The total-pressure loss across the screens (from 22 percent at Mach number 1.58 to 43 percent at Mach number 2.06) recorded at axial stations where the flow was considered most uniform was very high compared with the loss across conventional two-dimensional nozzles. The corresponding Mach numbers (approximately 80 percent of the nominal values predicted by one-dimensional isentropic theory over the range investigated) reflected, in part, these pressure losses.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, April 16, 1951.

REFERENCE

1. Royle, J. K., Bowling, A. G., and Lukasiewicz, J.: Calibration of Two Dimensional and Conical Supersonic Multi-Nozzles. Rep. No. Aero. 2221, S.D. 23, British R.A.E., Sept. 1947.

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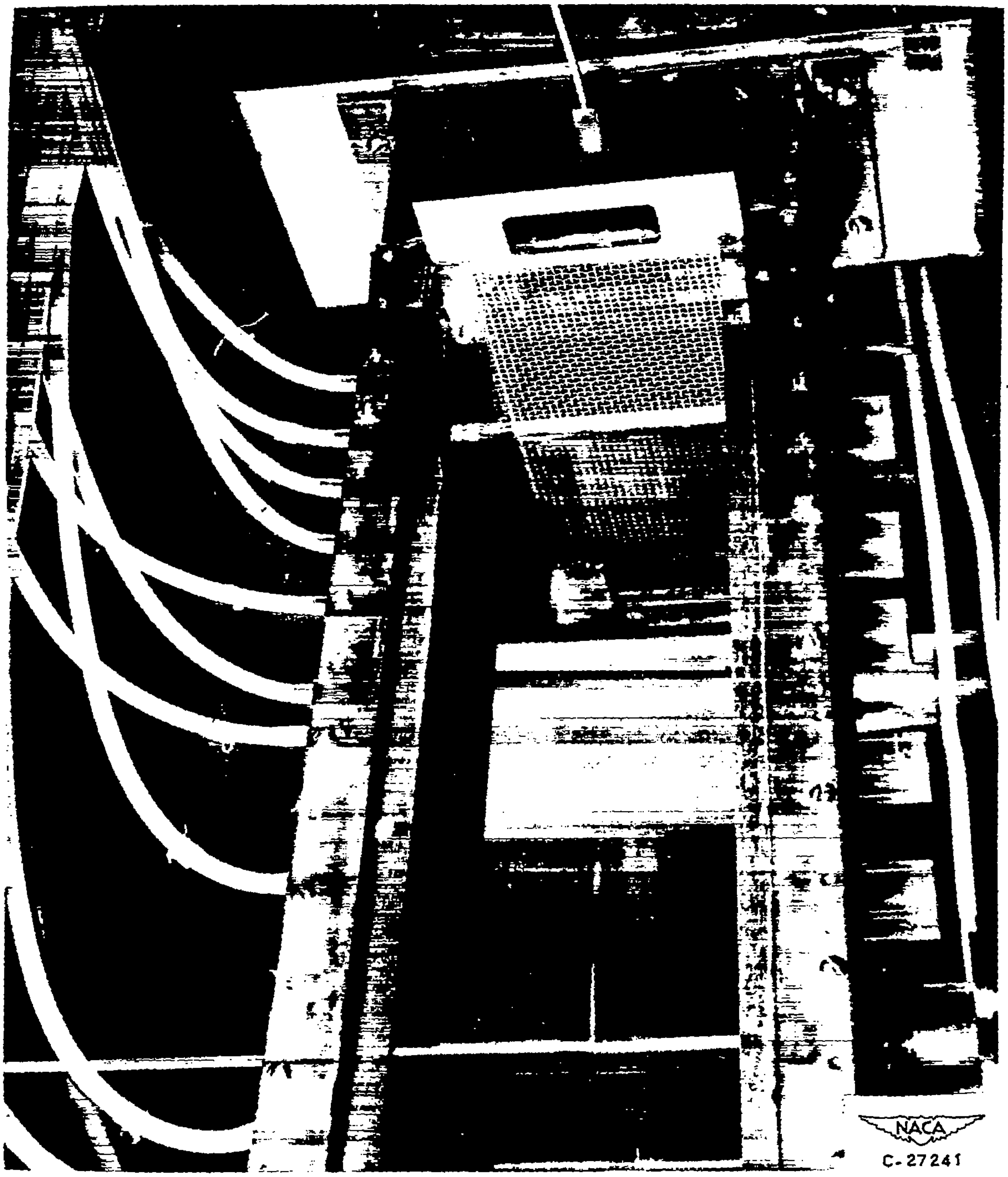
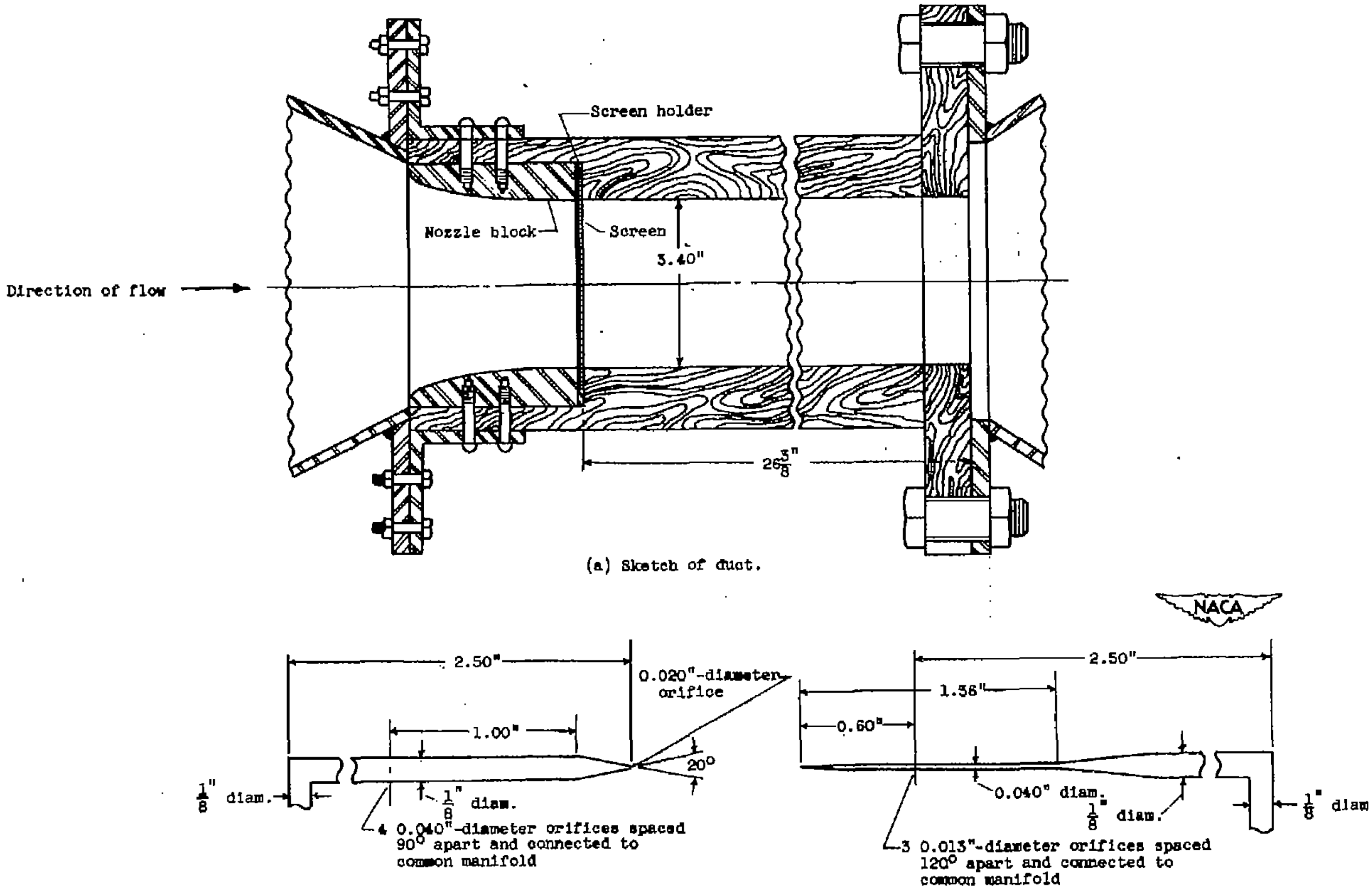


Figure 1. - Wire-mesh nozzle installation with pitot-static probe.

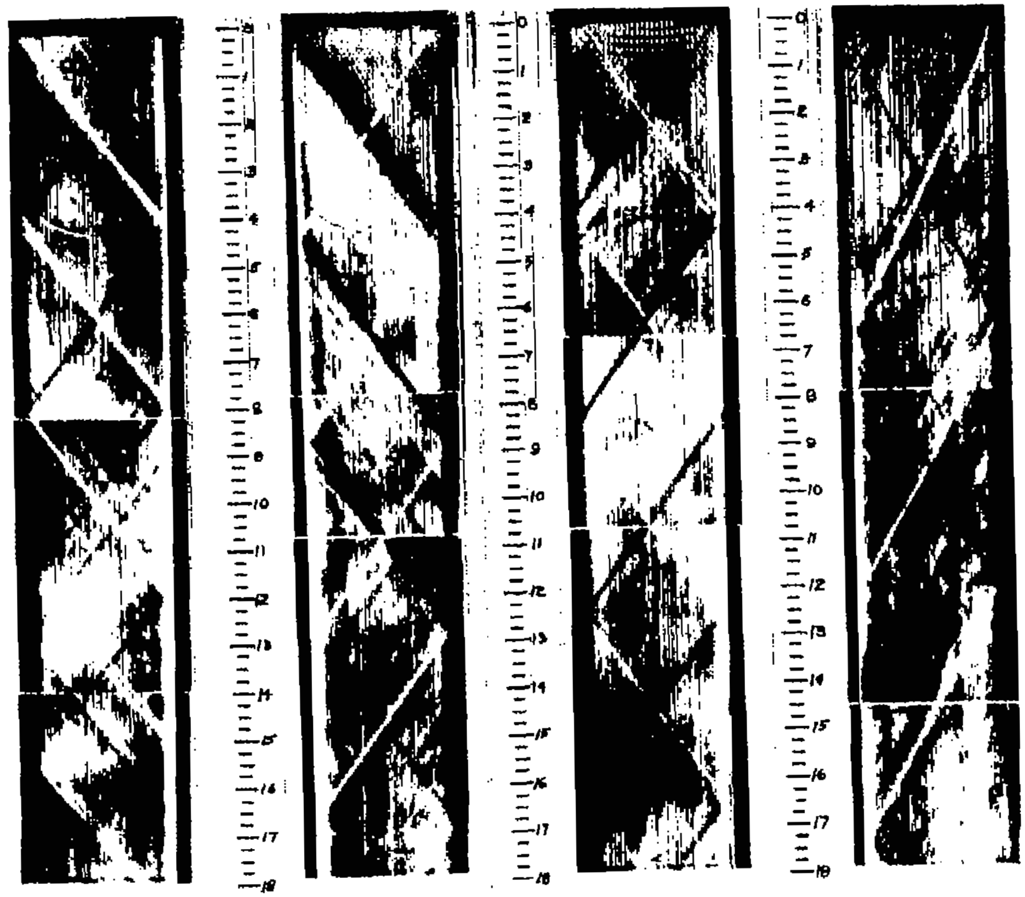


(a) Sketch of duct.

(b) Pitot-static probe.

(c) Static probe.

Figure 2. Sketch of duct, pitot-static probe, and static probe.



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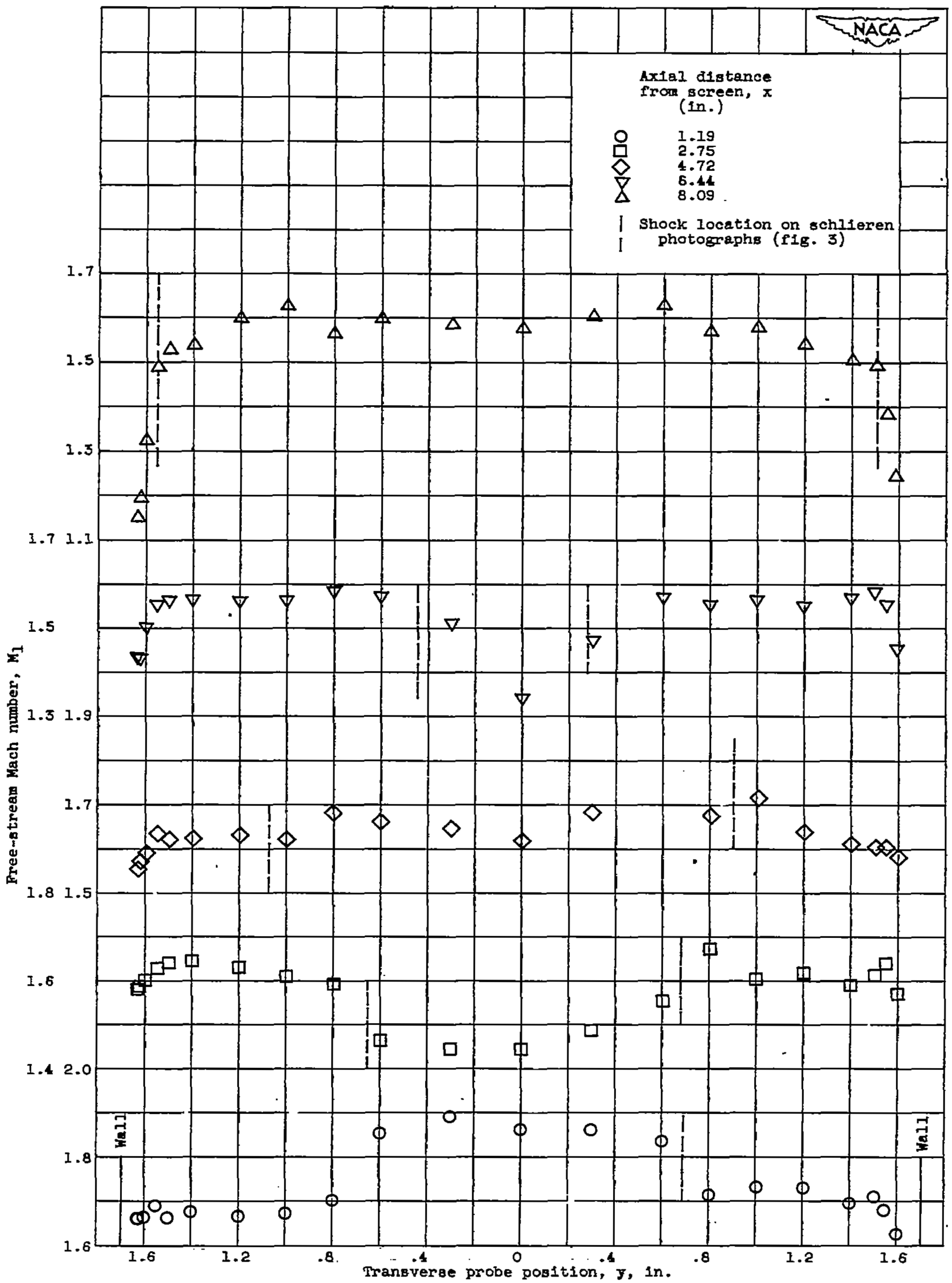
(a) Mesh, 20; wire diameter, 0.011 inch; nominal design Mach number, 1.97.

(b) Mesh, 18; wire diameter, 0.016 inch; nominal design Mach number, 2.18.

(c) Mesh, 9; wire diameter 0.032 inch; nominal design Mach number, 2.18.

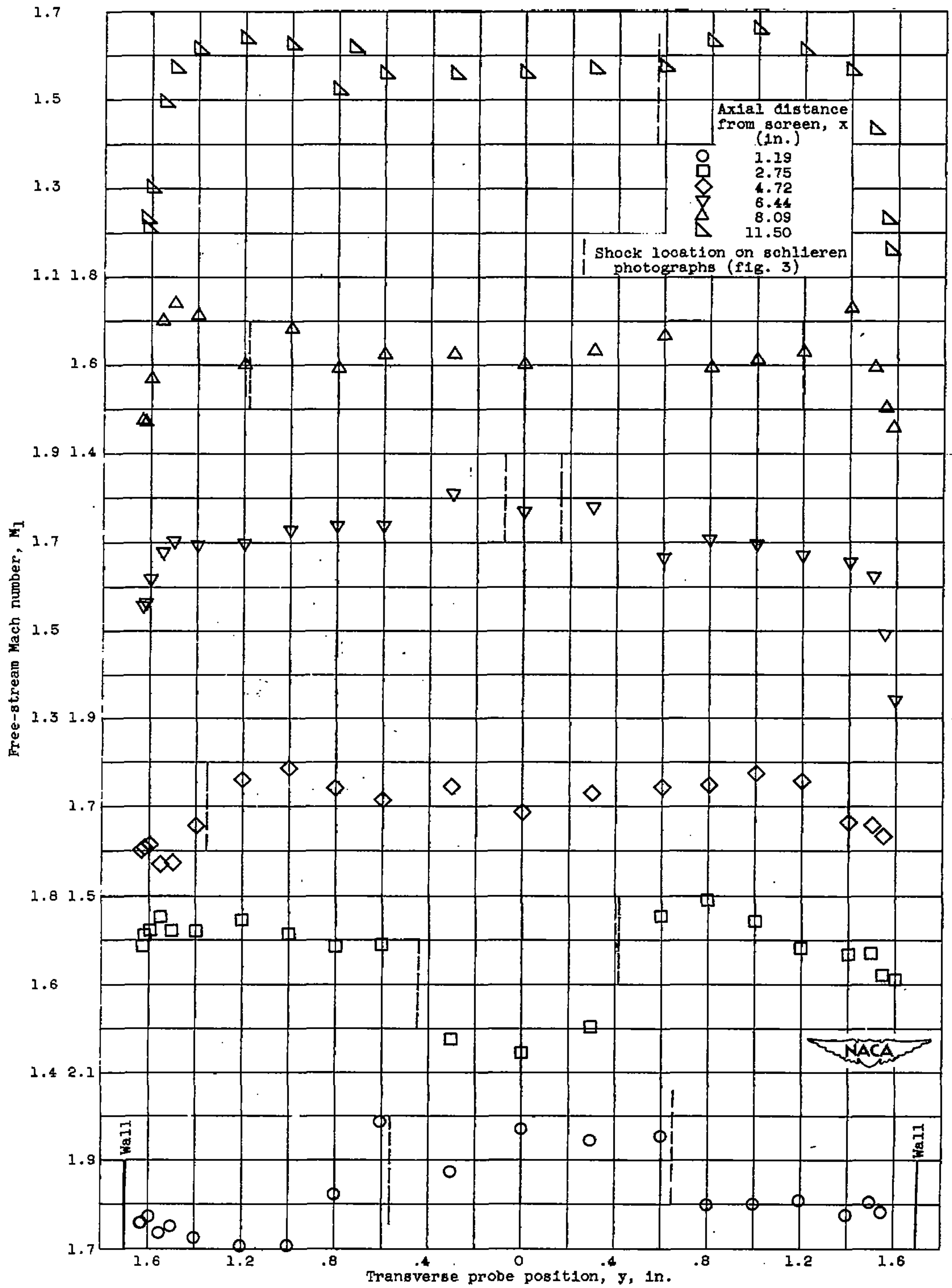
(d) Mesh, 15; wire diameter, 0.028 inch; nominal design Mach number, 2.58.

Figure 3. - Schlieren photographs of flow downstream of screens. (Scale indicates in. downstream of screen.)



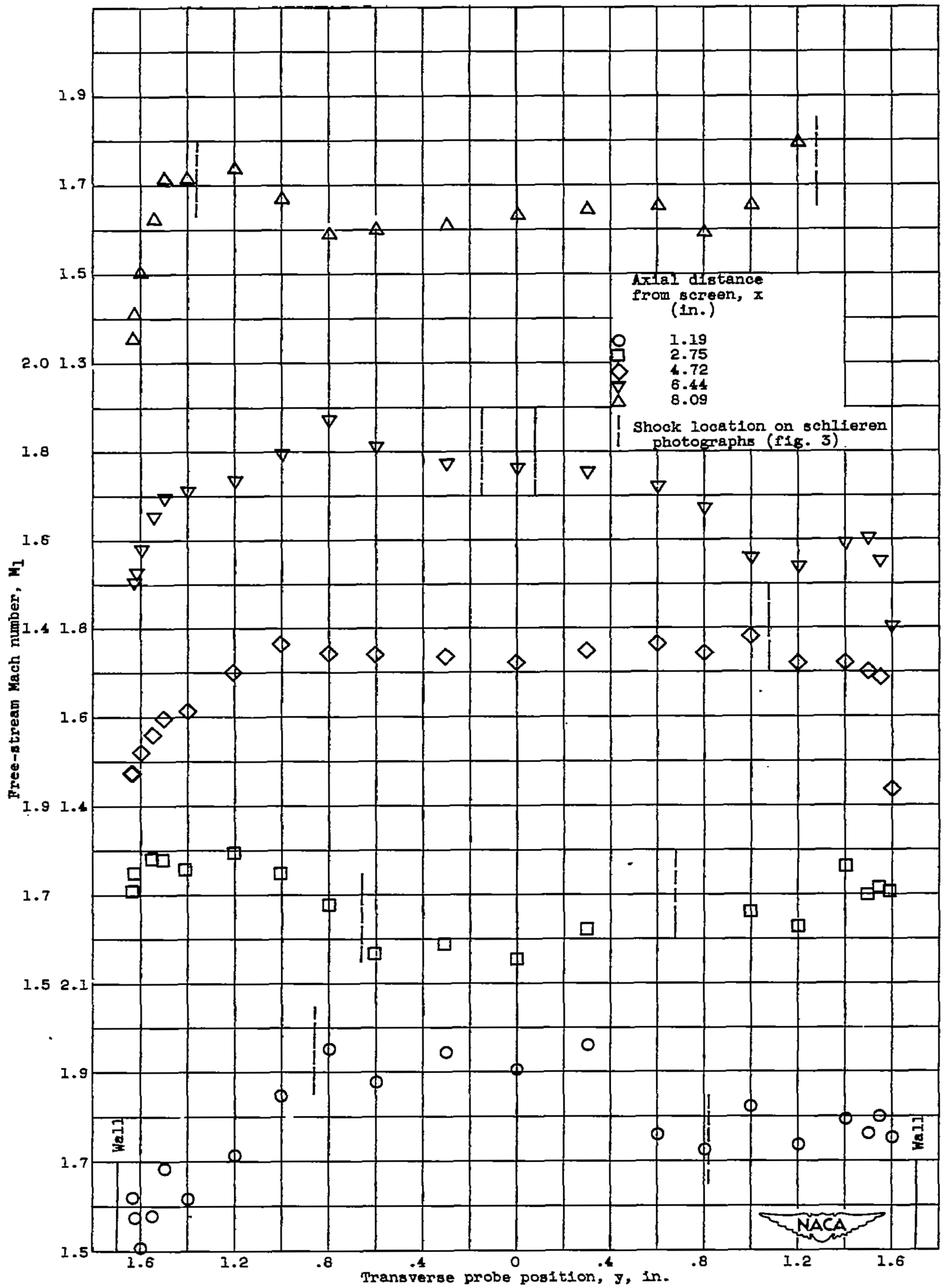
(a) Wire diameter, 0.011 inch; wire mesh, 20; nominal design Mach number, 1.97.

Figure 4. - Variation of Mach number along transverse center line at several axial stations.



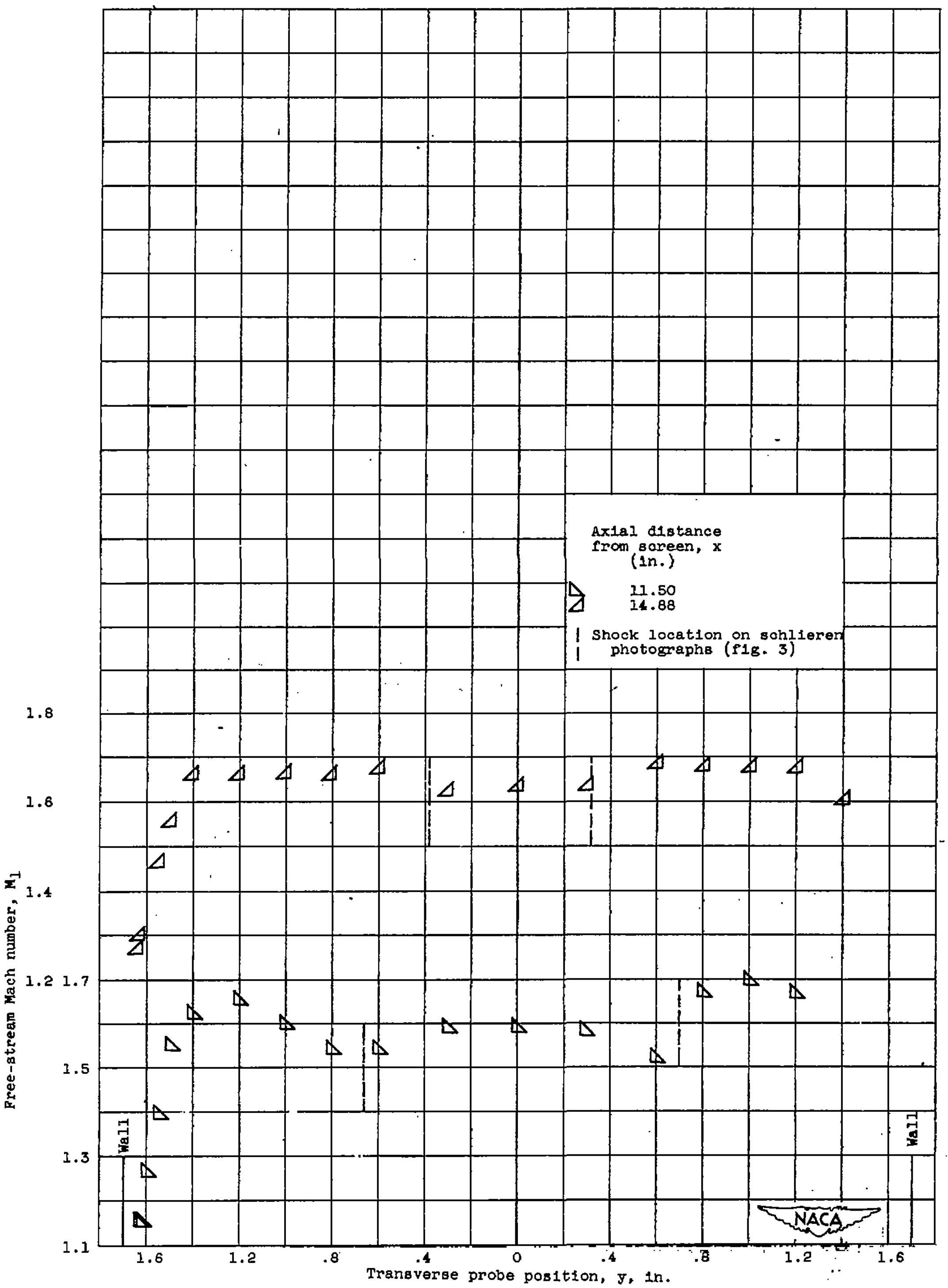
(b) Wire diameter, 0.016 inch; wire mesh, 18; nominal design Mach number, 2.18.

Figure 4. - Continued. Variation of Mach number along transverse center line at several axial stations.



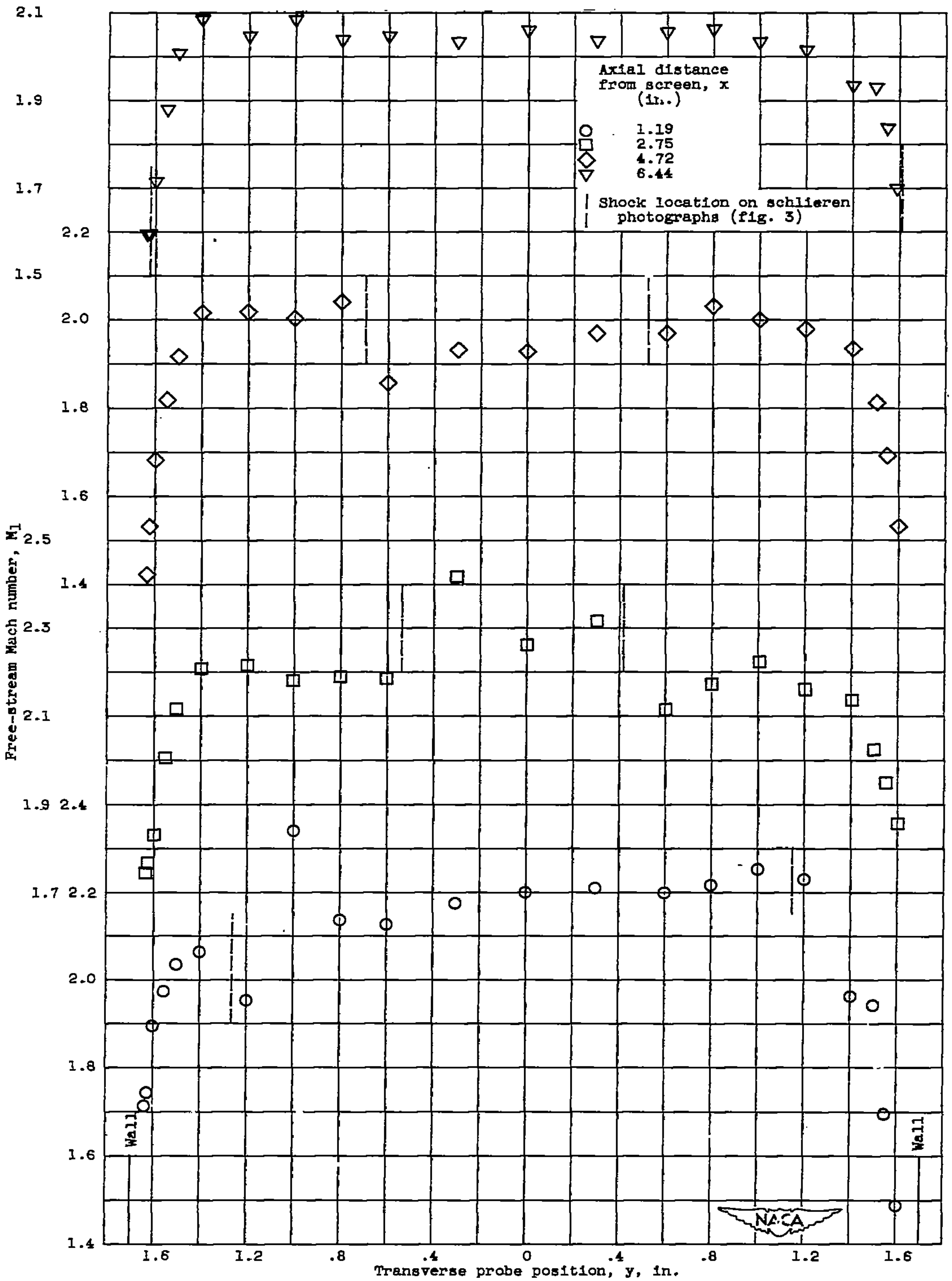
(c) Wire diameter, 0.032 inch; wire mesh, 9; nominal design Mach number, 2.18.

Figure 4. - Continued. Variation of Mach number along transverse center line at several axial stations.



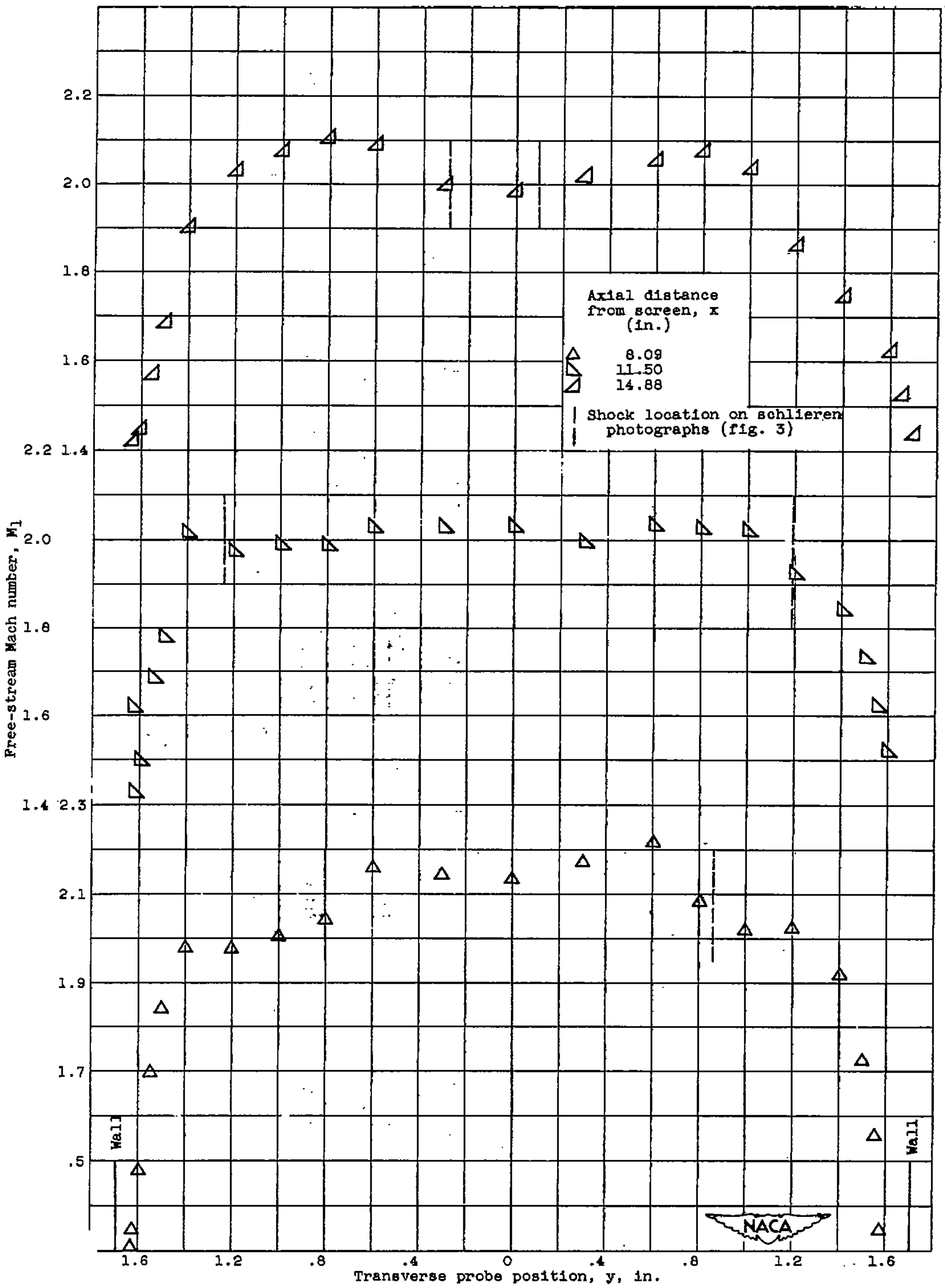
(c) Concluded. Wire diameter, 0.032 inch; wire mesh, 9; nominal design Mach number, 2.18.

Figure 4. - Continued. Variation of Mach number along transverse center line at several axial stations.



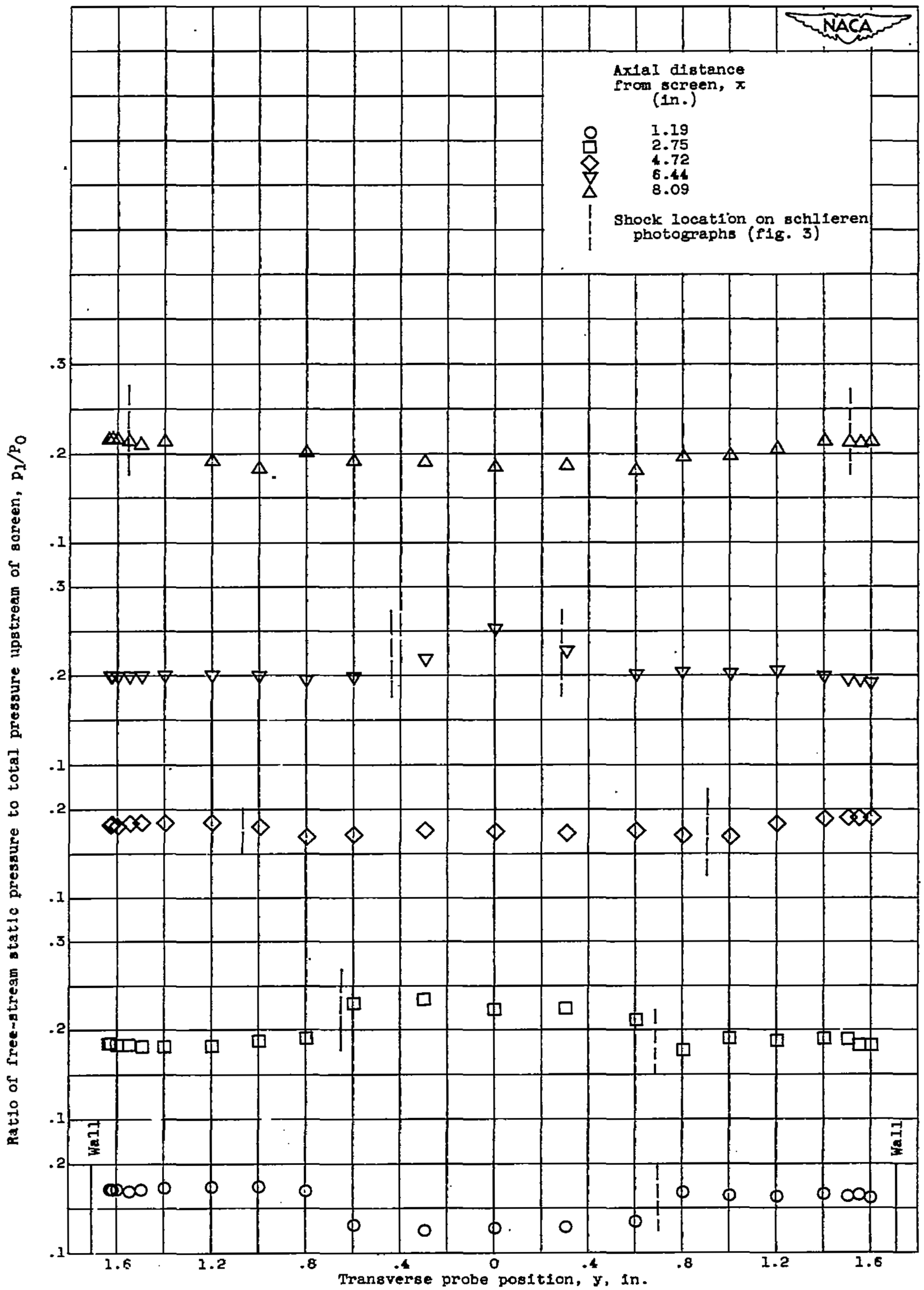
(d) Wire diameter, 0.028 inch; wire mesh, 15; nominal design Mach number, 2.58.

Figure 4. - Continued. Variation of Mach number along transverse center line at several axial stations.



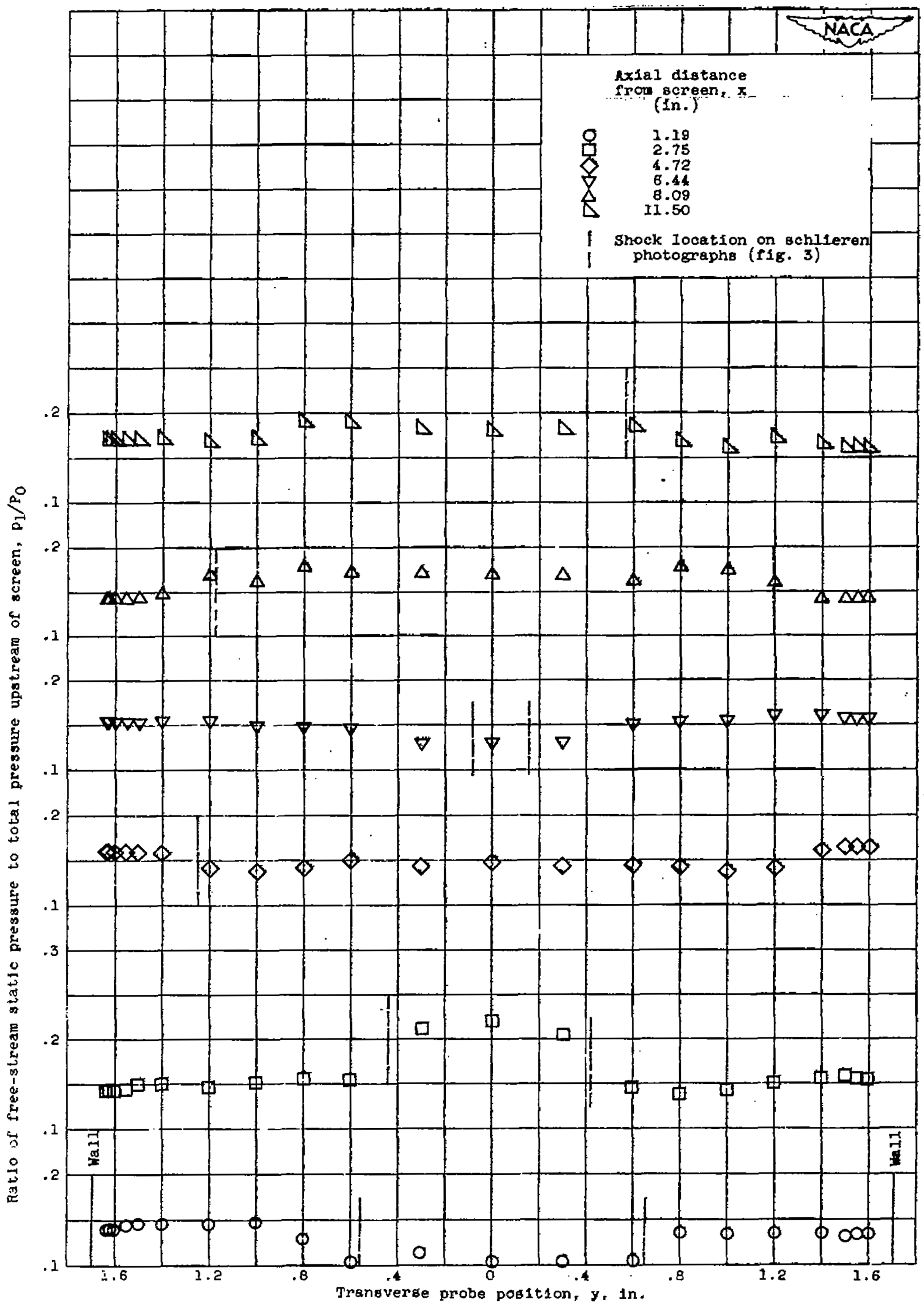
ncluded. Wire diameter, 0.028 inch; wire mesh, 15; nominal design Mach number, 2.58.

4. - Concluded. Variation of Mach number along transverse center line at several axial stations.



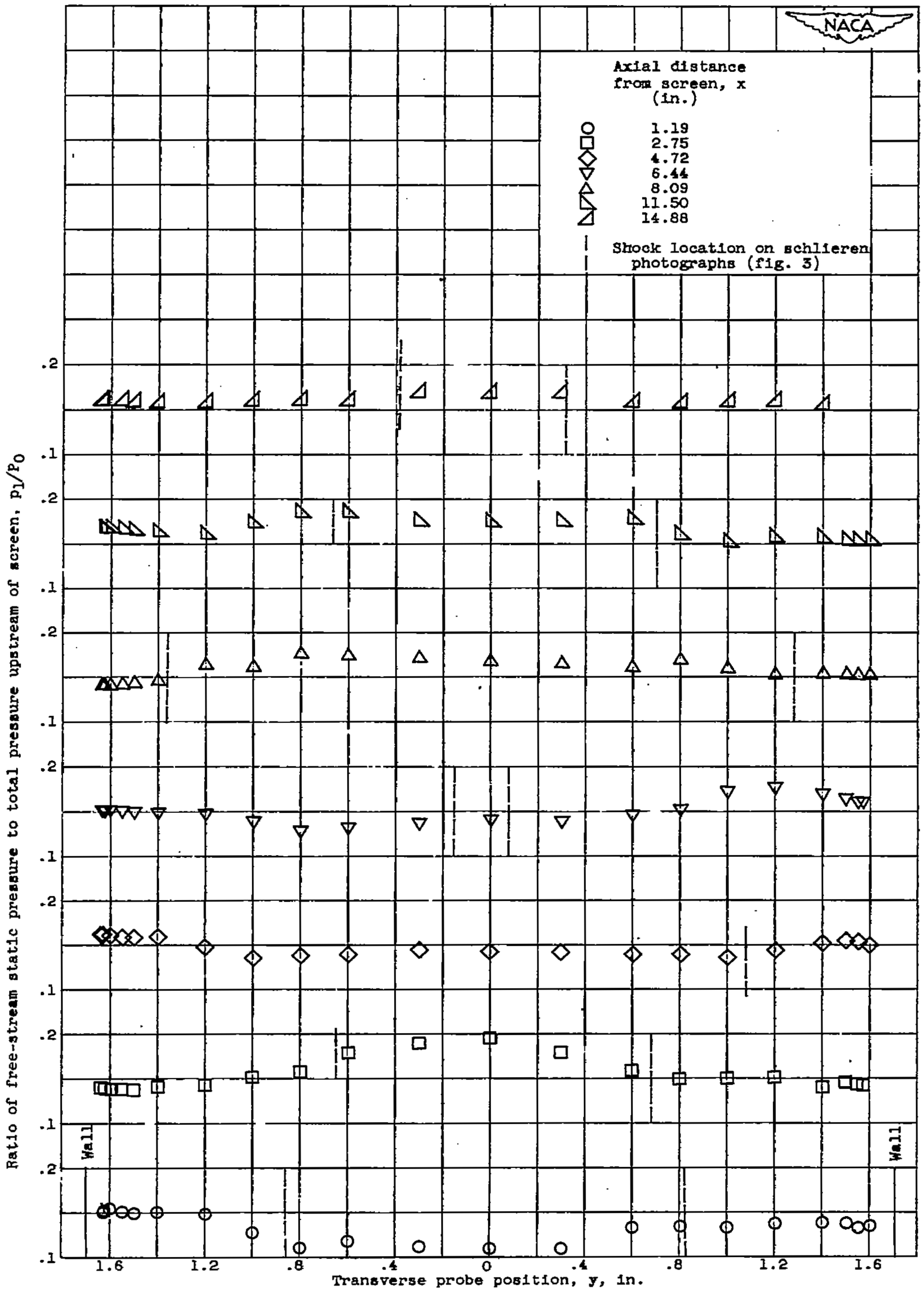
(a) Wire diameter, 0.011 inch; wire mesh, 20; nominal design Mach number, 1.97.

Figure 5. - Static-pressure distribution along transverse center line at several axial stations.



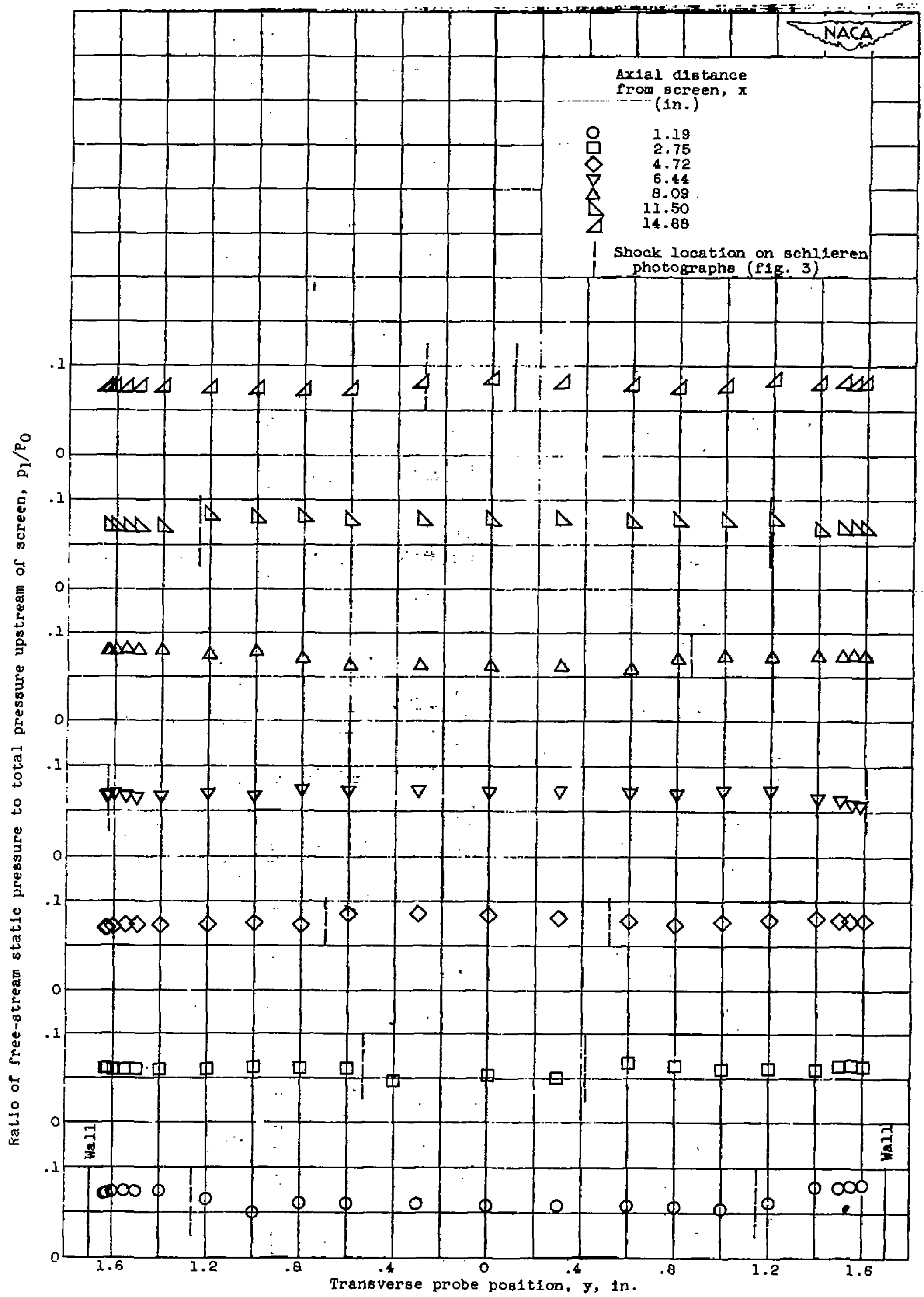
(b) Wire diameter, 0.016 inch; wire mesh, 18; nominal design Mach number, 2.18.

Figure 5. - Continued. Static-pressure distribution along a transverse center line at several axial stations.



(c) Wire diameter, 0.032 inch; wire mesh, 9; nominal design Mach number, 2.18.

Figure 5. - Continued. Static-pressure distribution along a transverse center line at several axial stations.



(d) Wire diameter, 0.028 inch; wire mesh, 15; nominal design Mach number, 2.58.

Figure 5. - Concluded. Static-pressure distribution along a transverse center line at several axial stations.

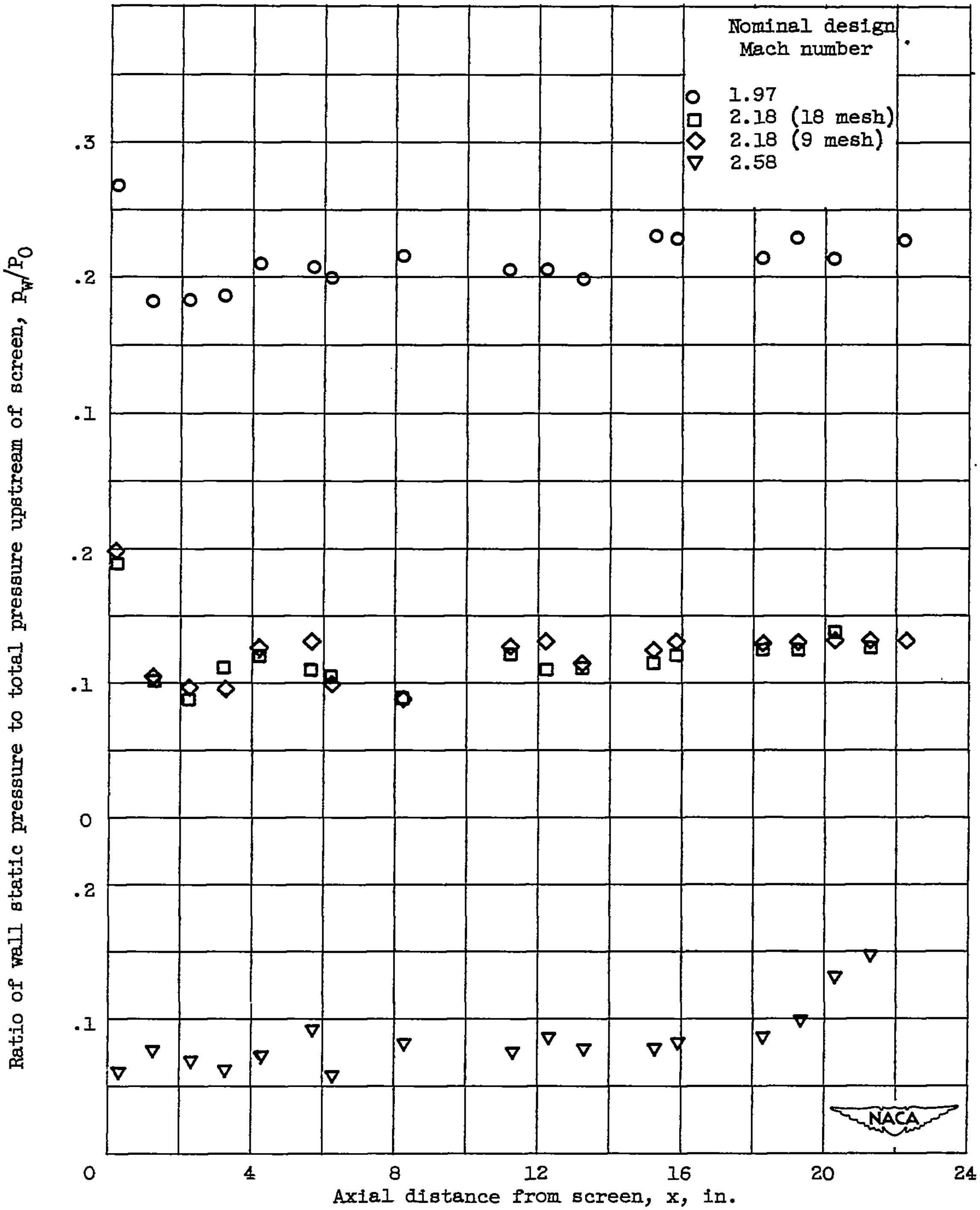


Figure 6. - Variation of wall static pressure with axial distance from screen.

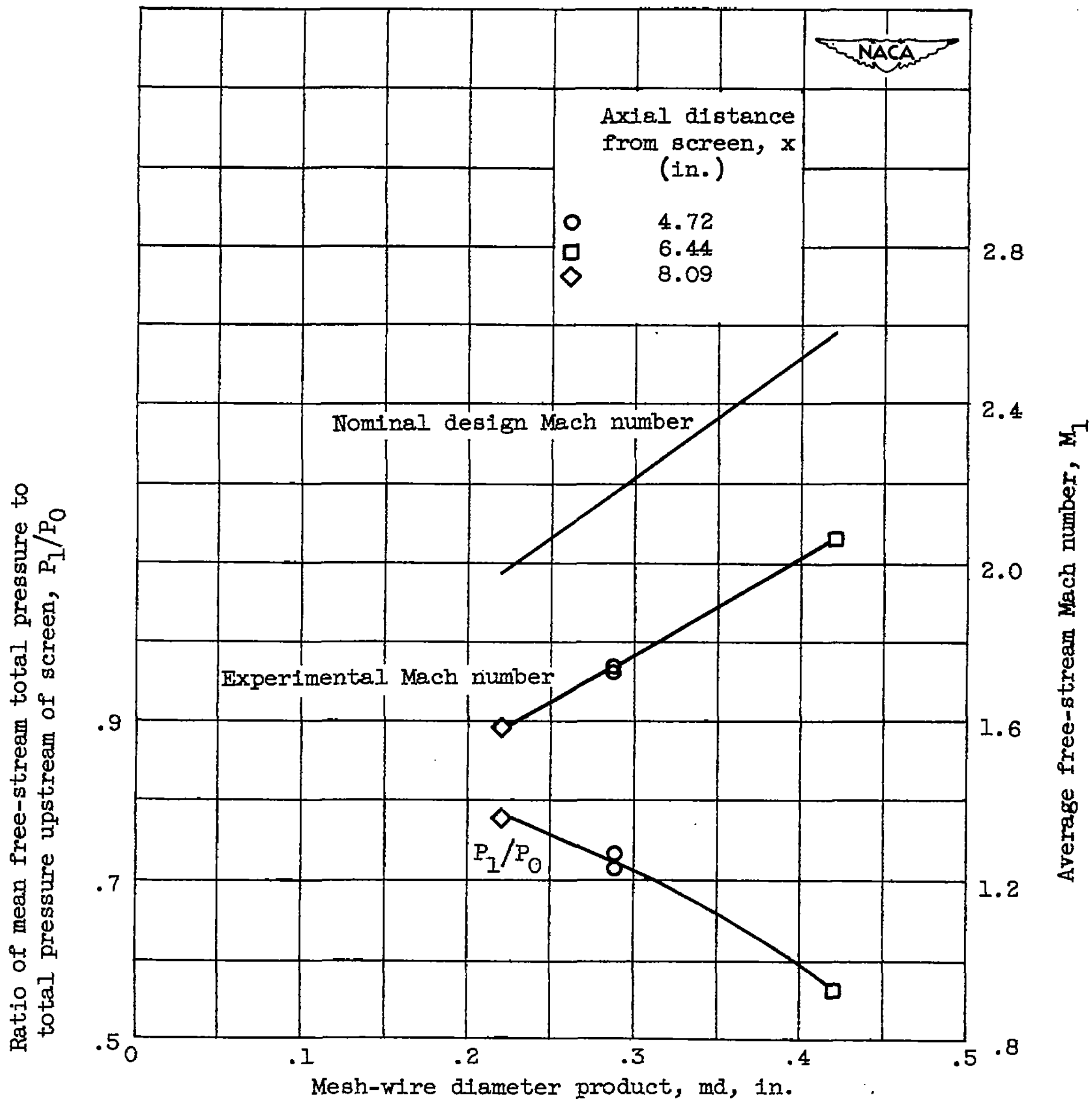


Figure 7. - Variation of total-pressure ratio across screen and average free-stream Mach number with mesh-wire diameter product.